HYDROLOGICAL AND SEDIMENT DYNAMICS WITHIN A SMALL CATCHMENT WITH BADLAND AREAS

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1. Introduction

Badlands are the main sediment source areas affecting the headwaters of the Gállego and Aragón rivers in the Central Spanish Pyrenees. These morphologies characterise the landscape of the Inner Depression, occupying about 15 km^2, which represent more than 2.5 % of the Inner Depression, and their occurrence is mainly associated to marly outcrops. Beguería (2005) suggested that Eocene Marls are the main sediment source in the Central Spanish Pyrenees, since this lithology is very sensitive to weathering and erosion processes.

Previous studies showed that the hydrological response and sediment yield in mountain humid badland areas are highly seasonal and are mainly controlled by regolith development (Regüés and Gallart, 2004). Moreover, rainfall intensity and rainfall depth are considered to be the most important factors in determining the hydrological and sediment response in badland areas (Mathys et al., 2005).

The aim of this work is to study the hydrological and sediment dynamics in a small catchment with badland areas by exploring the temporal variability of the hydrological and sedimentological response, and the relationships between hydrological and sedimentological variables.

2. Study area

The Araguás catchment has an area of 45 ha and it is located in the Inner Depression (Central Spanish Pyrenees), 8 km northwest of Jaca (Fig. 1). The highest divide reaches 1100 m a.s.l. and the outlet is at 780 m a.s.l.

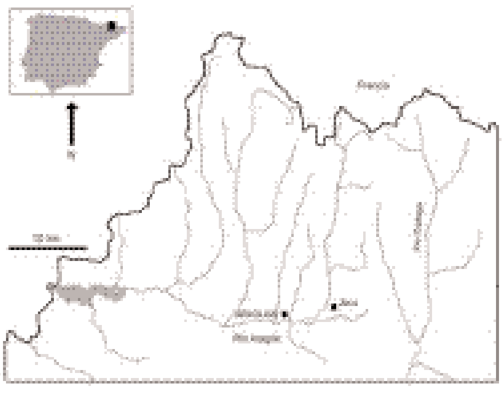

Fig. 1. Map of the localization of the Araguás catchment.

The rock substratum is composed of Eocene Marls in the lower part (massive marls and interbedded decimetre-scale sandy layers). In the upper part of the catchment the bedrock is Eocene Flysch (thin alternating layers of sandstones and marls).

The climate is defined as sub-Mediterranean mountain type with a mean annual temperature of about 10 ºC and mean annual precipitation of about 800 mm, mostly concentrated in autumn and spring.

Three different land cover types can be differentiated: badland areas, associated with the outcrops of Eocene Marls are located in the lower part; grasslands and meadows dominated the central part whereas the upper catchment is covered by dense forest plantation.

3. Equipment and methods

Instrumentation of the Araguás catchment started in 2004 in order to study weathering, erosion and transport processes. In October 2005, a gauging station was installed at the outlet of the catchment; the water level is measured using an ultrasound water-level sensor (Pepperl+Fuchs) and pressure-based water level probe (Keller DCK-22AA); the suspended sediment is measured using a turbidity meter (Endress+Hauser); furthermore, an automatic water-sampler (ISCO 3700) collect samples during flood events to evaluate sediment concentration and analyse for dissolved salts. All instruments are connected to a datalogger (Data Taker DT50) that scans the information every 10 seconds, recording the average value every 5 minutes.

Three tipping-bucket rain gauges (David Instruments) were installed from the lowest to the highest parts of the badland area (780 m, 800 m and 1000 m a.s.l.).

Finally, air temperature and two profiles of regolith temperature in north- and south-facing slopes were recorded and stored every 30 minutes.

Relationships between hydrological and sedimentological variables were analysed at the event scale through a linear correlation matrix.

4. Results

A total of 64 floods were recorded and identified within the study period (October 2005-January 2007). The Araguás catchment reacts to almost any rainstorm event. Most of the rainstorms were small in magnitude, with more than 80 % lower than 15 mm. The highest rainfall amount was 49.8 mm and the highest peak flow was 2046 ls^{-1} (rainfall amount in this event was 28.4 mm). Suspended sediment was always transported during floods and the highest

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suspended sediment concentration (SSC) was 1230 gl^{-1}. More than 50 % of the events exported less than 10 Mg but 3 extraordinary events exported more than 1000 Mg.

Fig. 2 shows two examples of flood hydrographs with their sedigraphs. The response was characterized by a rapid hydrological and sedimentological response, a relatively narrow flood peak and a steep recession limb. The peaks of suspended sediment concentration almost coincide or slightly precede the peak flow. Moreover, there is a good adjustment between the shape of the hyetograph and the hydrograph, suggesting a large contribution to overland flow processes (Fig. 2).

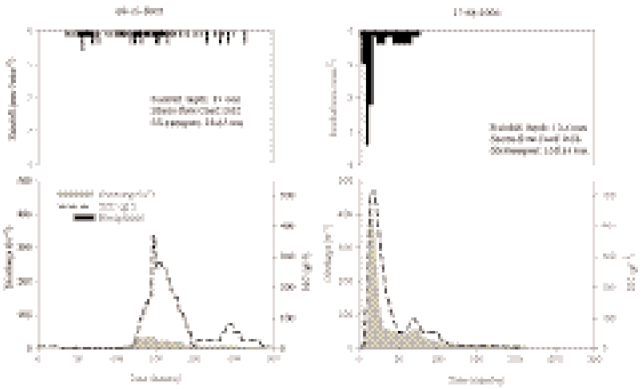

Fig. 2. Hydrographs, sedigraphs and hyetographs for two selected events of different magnitude in the Araguás catchment.

Table 1. Linear correlation coefficients between hydrological and sedimentological variables for the observed rainfall-runoff events. n=64 ** correlations are significant with p<0.01 and *correlations are significant with p<0.05.

	Storm-flow coefficient	Peak flow (ls^{-1})	Peak of SSC (gl^{-1})	SS transport (gl^{-1})
Rainfall depth (mm)	0.598**	0.686**	0.429**	0.638**
Maximum rainfall intensity (mm h^{-1})	0.192	0.657**	0.313*	0.261**
Baseflow (ls^{-1})	0.339**	0.398**	0.124	0.239
Peak flow (ls^{-1})	0.575**	1	0.377**	0.695**
Storm-flow (mm)	0.797**	0.673**	0.391**	0.793**
Rainfall depth 1 day before the event (mm)	-0.058	-0.021	0.125	-0.026

Table 1 summarises the linear correlation coefficients between some hydrological and sedimentological variables. Storm-flow coefficient show good relationships with rainfall depth, peak flow and storm-flow. No significant correlations were found between the storm-flow coefficient and rainfall intensity and rainfall recorded one day before the event. Peak flow was significantly correlated with all variables except with the rainfall recorded one day before. Finally, significant correlations were observed between maximum suspended sediment concentration and suspended sediment transport and rainfall depth, maximum rainfall intensity, peak flow and storm-flow.

5. Discussion and conclusions

This study shows the high variability of the hydrological and sedimentological response in a small catchment characterized by extensive badlands areas, as described in other previous studies (Mathys et al., 2003). One of the most relevant features of this Mediterranean catchment was its responsiveness, with very high suspended sediment concentrations and yield, closely related to badland development and dynamics (Regüés and Gallart, 2004). Correlation analysis indicated that no single variable was able to explain the hydrological and sedimentological response of the Araguás catchment.

The similarity between the hydrograph, the sedigraph and the hyetograph, as well as the rapid response of most of the floods, suggests a large contribution of the overland flow, mainly resulted from the generation of infiltration excess runoff on badland areas.

Badlands are one of the most erosive morphologies due to their superficial dynamics, mainly affected by the climatic seasonality. Marls are subject to strong weathering, as shown by the mean erosion rate estimated in the catchment, close to 2.9 cm $year^{-1}$. The dynamics and effectiveness of weathering processes related to erosion processes produce high suspended sediment values. In this way, each event in a badland area can be compared to many responses in vegetated areas.

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